Art. IV.—*Shingle on the East Coasts of New Zealand.*

By W. W. Culcheth, M. Inst. C.E., F.R. Met. Soc.

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1. The following has been written from observations lately made by the author in New Zealand. The conditions attending the shifting of the materials which form the coast in many places are of great interest to the engineer who has to design protective works or harbours in such localities. This paper deals more particularly with travelling shingle, a subject that has given rise to much controversy. So long ago as 1853 a paper on the Chesil Bank on the south coast of England was read before the Institution of Civil Engineers by Mr. (now Sir) John Coode, whose name is well known in these colonies. The late Astronomer Royal, Sir George Airy, took part in the discussion on that paper, differing in opinion on certain points from Sir John Coode. This discussion was renewed at intervals, and so lately as 1875 an agreement on the points of difference had not been arrived at. The opinion of those of the leading engineers who were not prepared to support one side or the other in these discussions, was that more information was required from other localities, and that it was unsafe to generalise from the results observed at the Chesil Bank.

2. In this paper a few facts only will be stated, with some deductions from them, the object being to direct attention to the subject in this part of the world, in order that more information may be collected and further light thrown on the movements of shingle under varied conditions. Sir J. Coode remarked in his paper of 1853 :—"There are few subjects of greater professional interest than the accumulation and travel of shingle, since the very existence of many harbours depends, in a great degree, upon a correct understanding and judicious application of the laws which govern its movement; and without a knowledge of these it is impossible to devise such measures as may with confidence be adopted, either to assist its progress, direct its course, or to remove accumulations that may have taken place."* Shingle

* See *Proceedings of the Institution of Civil Engineers*, vol. xii., p. 520.

is the chief subject of this paper; but the action of the waves on sand cannot be wholly neglected, as the difference is chiefly one of degree.

I.—Description of the two Beaches Visited.

3. The author visited what is known as the Ninety-mile Beach, on the east coast of the South, or, as it used to be called, the Middle, Island, and the beach near Napier, in Hawke's Bay, on the east coast of the North Island.

4. The Ninety-mile Beach extends from Banks' Peninsula in a south-west direction to Timaru, but the same beach really extends some 50 miles further down the coast in a southerly direction to Oamaru. There is an uninterrupted shingle beach over 130 miles in length. The principal source of supply of this shingle is the River Waitaki, or, as it is called on the Admiralty chart, the Waitangi, which is about 14 miles north of Oamaru. "Cliffs from 30 to 40 feet high" are marked on each side of the mouth of this river. Some of the shingle is said to come from these cliffs. The shingle on the beach opposite Oamaru is evidently driven there when the wind is north of east. South-easterly weather would formerly tend to denude the beach, but since a breakwater has been constructed at that place shingle has been collecting opposite the town. It is said that the accumulation near the mole on the north side of the new harbour has ceased; but this may be only temporary. The same agency which caused the present accumulation is still at work. North-easterly weather must continue to drive shingle down the coast from the River Waitaki, and unless the mole causes the shingle to be deposited at a point sufficiently distant to allow of its being carried back during south-easterly weather the accumulation must go on, though it may be but slowly.

5. South-easterly weather prevails on this coast, and as the beach between Oamaru and the River Waitaki is supplied chiefly from that river, which is to the northward, this beach is probably at times denuded, the cliffs being then cut away. The beach between the river and Timaru is probably less subject to change, owing to the chief supply of shingle being at the end from which the prevailing seas come.

6. South-west of Timaru, at the end of the town, is Patiti Point, where there is a low cliff with a shingle beach n front. It is at first difficult to account for the beach

existing at this point, and for the cliff, which is composed simply of earth, not being cut away; but there is a sunken reef running some distance out to sea in front, which evidently protects the cliff in bad weather. The beach can take care of itself, and can also protect the cliff at ordinary times. North of this is another reef, but of less extent; it shelters the harbour somewhat from heavy south-east seas.

7. At Timaru a breakwater is being constructed with a view of making the harbour more safe than hitherto. This work has given rise to much controversy from the fact of its being in the middle of a beach of travelling shingle. Sir J. Coode gave a design for a breakwater and harbour detached from the shore to allow of the shingle travel going on uninterruptedly. The plan was not locally considered satisfactory, and a solid breakwater running out from the shore was resolved upon instead. This work is now going on. At first it was proposed to construct a length of some 400 or 500 feet only; but it being found that the shingle was likely to get round the end of the work, its length was increased, first to something less than 1000 feet, the author believes, and then to 1400 feet. The latter length has now been constructed, and the result is, in Timaru itself, generally considered very satisfactory, the shingle having been driven back by the waves reflected from the breakwater. After the work had been carried out to a length of something over 700 feet, the shore line at high-water level began to recede, and continued to do so for a year or more. It has since advanced a little, but this is probably of no great importance, as changes must be expected, according to the weather. Occasionally, during a gale, the shingle is thrown up on to the top of the breakwater, which is 6 feet above high-water level. The shingle would be carried over the work were it not cleared away by manual labour.

8. A far more serious point is that an accumulation is taking place a few hundred yards away from the breakwater, where the reflected waves cease to have any effect. The Government engineers and others who were opposed to the work from the first, expressed the opinion that in time shingle would swamp the work, and render the harbour useless. Various periods of time, some extending as far ahead as twenty years, were allowed before this should take place. The people of Timaru, however, laugh at these opinions, and consider the work will be a success. It is not denied that shingle continues to come up the coast, but the breakwater

having kept back the shingle some four years or more, it is hoped that it will do so always. They do not ask what becomes of the shingle, or what will become of it in course of time. The action at Napier, which will be mentioned presently, may prove instructive in connection with this matter. (See pars. 13 and 14.)

9. Another result of the construction of the breakwater at Timaru may be mentioned to show that travelling shingle cannot always be obstructed without some evil following. When the shingle was stopped by the breakwater the beach in the bay in front of Timaru was entirely denuded, and a serious erosion of the banks commenced. Very heavy expenditure has been incurred in throwing down large blocks of stone along the shore to protect the railway from being destroyed. It was at one time even proposed that the breakwater should be cut through to allow of shingle passing as before. This was not done. The denuding of this beach occurred before the breakwater had been carried out far enough to shelter the beach from the action of south-easterly seas, although it was sufficient to keep back shingle coming up the coast from the south. The bay is now more sheltered, and will become more and more so as the breakwater is carried further out. The northern part of the bay is, however, exposed to seas from the east and north-east, which must carry shingle down the coast, contrary to the general direction. There is shingle less than 1½ miles up the coast, in front of the Waitarakao lagoon. Some of the shingle so carried down the coast is likely to come under the shelter of the breakwater, so that it will not be carried up the coast again by south-easterly seas. Shingle will then begin once more to accumulate in front of the town as at Oamaru. This result may already have commenced, although possibly there is too little shingle to have attracted notice as yet.

10. Between Timaru and Banks' Peninsula there are several rivers, against four of which it is noted on the chart, "Mouth always open;" the others are probably closed except during freshets. The author does not know whether these rivers bring down further supplies of shingle or not; probably they do, for the whole of this part of the country is said to have a substratum of shingle. The beach is, however, continuous up to Banks' Peninsula. The last twelve or thirteen miles, in front of the Waihora Lake (also called Lake Ellesmere), is really a broad neck of shingle, in some places nearly a mile in width. This encloses a large sheet of water,

marked "Very shallow and brackish." The bed of this lake, and the bank in front of it, represent the shingle accumulation since the present beach began to be formed. The author was informed that a series of ridges are to be seen where probably the beach has been in successive periods, and at the extreme end the shingle has been thrown up against a cliff to a height of 30 feet above sea-level.

11. The advance of shingle beyond this point is prevented by the trend of the coast-line changing suddenly to east-south-east, so that shingle could not be carried on unless by a sea coming from the west-south-west, or a more westerly point, which would be directly along the shore or off-shore. Waves of any size could not therefore be formed; and should any small quantity of shingle be carried forward by these waves, it would be carried back by a change to the south-east, the prevailing direction.

12. The shingle beach in Hawke's Bay extends from eleven miles south of Napier to ten miles north of that place, where a projecting cliff arrests the steady advance of the shingle. Beyond this cliff is a beach, partly of sand and partly of shingle, for a further length of over thirty miles, the general direction being north-easterly. The chief source of supply of the shingle is the River Tuki Tuki; and the prevailing direction of the seas on this coast, as on the Ninety-mile Beach, is south-easterly, but north-east seas at times cause great changes in the shingle. The general movement of the shingle, from the mouth of the River Tuki Tuki as far as Napier, is due to seas coming from any direction south of east. For some distance south of Napier there is merely a narrow belt of shingle, forming the only connection between the mainland and the town, the high part of which was formerly known as Scinde Island. It is, indeed, asserted that Captain Cook sailed round this island. If this be correct, the shingle accumulated in the neighbourhood is but of recent growth. Beyond the Bluff, at Napier, the south-east seas have very little effect, and the chief movement is due to seas coming north of east.* From the exposed position of the Bluff, the beach below it is liable to change very much. It would, doubtless, often be entirely denuded of shingle but for the protection afforded by large blocks of stone which have fallen into the sea from the cliff.

* The difference, at times, between the direction of the wind and that of the waves must not be overlooked. (See App. *b*, p. 81.)

13. One mile and a quarter west of the Bluff is the entrance to the present harbour. To improve this, a few years ago, two moles or jetties were run out into the sea. As that on the east side of the entrance was being constructed the shingle, for a time, advanced with the work. At last " the work got ahead of the shingle, which gathered at a much slower rate; but although the high-water line did not advance, the shingle at low-water line was spreading further out." The waves reflected from the work drove back the shingle along the shore at the high-water line a distance, at first, of about 800 yards, which gradually was reduced to 500 yards. The shingle here accumulated for a year or more, when "a very heavy north-easterly sea set into the bay," and this "accumulation of shingle, &c. . . . . advanced right up to the mole within the space of two days."

14. Such was the end of this attempt to keep back the shingle. The mole projects a less distance out than the breakwater at Timaru does, but the result at Timaru must in the end be similar, though it may take a longer time. There is one other difference between the two cases. The mole at Napier is sheltered from south-east seas, though the swell is felt. The breakwater at Timaru is also sheltered from the full force of heavy south-east seas, but sufficient wave-action from that direction is felt to cause the shingle to advance. It is difficult at present to estimate the different results likely to ensue from this difference, but it is not likely to alter much the final result, unless, in the case of Timaru, the advance be more gradual than at Napier. It may be remarked that, in the same way as at Timaru, shingle is, in bad weather, thrown up on to the mole at Napier, the top of which is also 6 feet above high-water level. Not being cleared away, the shingle is washed completely over the mole.

15. After passing the entrance to the present Napier harbour there is now a large accumulation of shingle, which is mainly due to the shelter afforded by the western mole. After this there is a long spit of shingle, the trend of which gradually changes from north-west to north, enclosing a large lagoon, called the Ahuriri Lake. The spit joins the mainland four miles from Napier. Seven miles further on, after enclosing another small lagoon, the beach ends at the cliff before-mentioned. This cliff projects from the mainland for about a mile, in an east-south-east direction. As

this is almost at right angles to the beach, no waves of any size can be formed to carry the shingle along it. The advance of shingle beyond this point is probably due to the cutting-out action which takes place at times, the finer material being drawn under the water-line by certain waves. On this point more information is required.

16. The largest stones, or pebbles, which composed the shingle seen by the author in New Zealand seldom measured more than 6 inches by 4 or 5 inches by 3 inches. Several stones, measuring a third or so more each way, were seen near the mouth of the River Waitaki. The usual size of those on the beach was, however, much less than above stated; occasionally, near Napier, it was little more than that of coarse sand. These stones have, evidently, from their rounded appearance, before being thrown on to the beach, been subjected to the action of water in a former age, and are now found embedded in earth. They are chiefly derived from the rivers already mentioned, down which they are carried during freshets.

17. A further source of supply is in the mountains in which the Canterbury rivers have their source, where there are "long slopes from 500 to 1000 feet high, as regular as the slopes of a railway embankment, and formed entirely of clay-slates, broken up to the size of road metal; the stone lies at an exact angle of repose, and if a shovelful were taken from the foot the movement would extend to the top of the slope. . . . Even where the rocks are not actually broken up, they are so easily disintegrated that every small stream forms a large fan of shingle when it reaches the valley. During floods the streams cut deep gulches through these fans, carrying the shingle away into the main river." The inclination of the bed of the River Waitaki "is between 30 and 40 feet per mile, while that which the bed of a river of the same size would take if no new shingle were brought into it would not be greater than 3 or 4 feet per mile."* The cliffs along the coast, particularly on the South Island, are said also to furnish a large portion of the supply of shingle.

18. The banks of the rivers are very subject to erosion, and great changes frequently take place in the course of

* See New Zealand Parliamentary Paper, No. 2, of 1880, pp. 10, 11. Evidence of Mr. Carruthers, Engineer-in-Chief, relative to the Oamaru and Timaru Harbour Works.

some of the rivers. During floods, the material cut away from the banks is carried down stream, and a portion is deposited where the force of the current is diminished from any cause. The beds of the rivers above mentioned are strewn in places with stones and pebbles of all sizes. As the force of the stream is reduced and becomes insufficient to keep material in suspension, it is thrown down; and thus it is at the mouth of the rivers the largest deposit takes place. The stones and pebbles are there thrown in a large mass on the shore, almost, sometimes quite, blocking up the mouth, while the earth is carried away into the sea. Soundings show that much stone (described as gravel on the charts) is also carried into the sea; but a great deal of this is doubtless thrown up again on to the beach, as the author will endeavour to show later on. The material is mostly a bluish-grey stone, usually described as clay-slate.* The shape of the stones, or, more correctly, pebbles, may be described as flattened ovoids.

II.—Agency by which Shingle is Caused to Travel.

19. Material once deposited as above must, owing to its *vis inertiæ,* remain till some greater force than that of the current from which it was deposited comes into play. That deposited in the river bed may be removed by a succeeding flood; that near the mouth of the river may be removed by a greater flood than the first one; but the disturbance by floods of the material once deposited in the sea or on the seashore must be limited. The action of the sea itself must be looked to for any further movements of the material. In the sea two forces may be considered—(1) currents, which may be tidal or otherwise; and (2) waves. Currents along a coast, unless in exceptional localities, are usually of no great velocity, and, consequently, able to transport the finer materials only. The tidal flow into and out of an estuary, creek, or lagoon may be strong, and capable of moving large and heavy bodies, like a flood of similar strength in a river; but the action fails soon after the current enters the sea, in the same manner as the flood of a river then loses its force. With the exception of this tidal flow into and out of rivers

* Most of the stones from both coasts show, when fractured, a silicious composition. Some stones, frequently found near Napier, are evidently from a sandstone formation.

and lagoons, the author does not know of any current of much strength on the coasts to which this paper more especially relates. The wave-action, then, is the chief agent concerned in the transport of the shingle along the Ninety-mile Beach, and near Napier.

20. The power of waves during a heavy sea is sometimes extraordinary. At the Plymouth Breakwater, blocks of stone weighing several tons each have been washed from the sea-slope over to the land side of the work. At Wick, a mass of concrete and stone, weighing nearly 1400 tons, was, in 1872, gradually slewed round by successive strokes of the waves until it was finally removed from its place and deposited inside the pier. During one storm, "two stones, of 8 and 10 tons in weight respectively, had been carried over the parapet and lodged on the roadway of the breakwater." During a heavy gale on the west coast of Scotland, in 1829, waves were observed to exert a force of nearly 3 tons per square foot. At the south-east end of the Chesil Bank pebbles have been thrown to a height of 42 feet above high-water level. Numerous other examples might be given, but these will be sufficient to show that a very moderate sea is likely to be sufficient to move pebbles of the size above given and weighing not more than 7 lbs. or so. Professor Rankine gives a table* showing that large shingle is moved by water having a velocity of 4 feet per second *close to the bed,* which would ordinarily be equivalent to a surface velocity of, say, 5 miles an hour. This velocity might, under favourable conditions, be generated by waves of one foot or so in height. Little is, however, known accurately of the actual power of waves to move stones of given sizes. The author has observed pebbles of about the above weight (say 7 lbs.) not to be moved by waves of 2 to 3 feet in height; but this might be partly due to a thin edge of the stone being exposed to the water. Again, stones which have resisted the force of several waves in succession may be suddenly removed by a wave apparently no larger than those immediately preceding it.

III.—Action of Waves on a Beach.

21. The *tendency* of wave-action is, when not otherwise expressed, referred to in the following remarks on this subject. The actual effect is that due to the resultant of the

* See *Civil Engineering*, 9th ed. (1873), p. 708.

several forces at work. The real difficulties of the subject lie in apportioning to the several forces at work their relative value, so as to obtain a proper resultant, and, more particularly, in ascertaining what force is required to move materials of a given size and weight, and where such materials will be deposited as the power of the water to retain them in suspension is destroyed.

(a.) How Shingle is caused to Travel along the Shore.

22. Waves before breaking, being waves of oscillation merely, have, in general, very little effect on the material forming the bed of the sea. After the waves have broken they become waves of translation. On a wave breaking on any shore, or on a wave which has broken at a distance reaching the shore, a large quantity of water is, as every-one may have seen, thrown forward and flows up the slope, gradually decreasing in velocity till it reaches a certain point, from which it flows back down the slope. The water falling from the crest of a wave, on breaking, stirs up some of the material forming the beach. This will take place to a considerable extent if the water fall directly on to the beach, but to a less extent if it fall on to a cushion of water of some thickness. In the former case, a portion of the material disturbed is carried up the slope by the force of the water, and probably some material is carried by a back current (or under-tow) down the slope under the water-line. In both cases the return wave also will carry some material, when not too large, down the slope with it.

23. If the waves come directly on-shore, the material is carried alternately up and down the slope in lines nearly at right angles to the shore-line, so that the position of the particles laterally is altered but little. If, however, the waves come obliquely on to the shore, the particles are carried up the slope obliquely, and, on being washed down again, are somewhat in advance of the position they first occupied, the advance corresponding with the motion of the waves along the shore. The more acute the angle, within certain limits (probably about 45°), at which the waves strike the shore, the greater the advance of the material at each movement.

(b.) Wave-action on a Beach under various conditions.

24. When a wave breaks on a shingle beach and carries stones up the slope, these stones will be gradually deposited as the velocity of the water decreases, the largest first and

the smallest where the force of the water is least. The return wave will increase in force as it descends the slope, and it will gradually remove larger and larger stones till its force be checked. The steeper the slope the more rapidly will the on-shore wave be destroyed, and the more rapidly will the return wave increase in force; and *vice versâ*. Whether the return wave can remove and carry down the slope as large stones as had been deposited by the on-shore wave, or not, will depend on the slope of the beach. On a flatter slope than usual, the return wave will not acquire sufficient force; but, on a slope steeper than ordinary, it will doubtless acquire the force. Under certain conditions, all the largest stones are deposited at the highest level; under certain other conditions, at the lowest level. It must be noted that the return wave flowing down a slope is not destroyed on meeting an on-shore wave. The two waves cross, and the return wave continues its course away from the shore, gradually becoming less and less.

25. It was remarked just now that a wave breaking on, or close to, the shore stirs up the material of the beach, and doubtless some material is also carried by a back current down the slope under the water-line. This is a very important point to consider; the more so, as it is difficult to observe clearly this action on the material of which the beach is composed. A floating body may be seen on the point of being thrown by the waves on to the beach, when it will be suddenly drawn under the surface of the water, and will in a short time reappear some distance off the shore. When a wave breaks, it is probable that the particles of water in the trough of the wave continue the backward (off-shore) motion they had immediately before the wave broke. If such be the case, each wave breaking *on* the shore, or so close to it for this backward motion to be felt on the beach, has a tendency to draw under the water-line some of the material disturbed, as well as to carry material up the slope, as above explained.

26. If an on-shore wave break at a distance from the shore, and on to a considerable cushion of water, the backward motion of the water in the trough of the wave is not likely to have any appreciable effect on the material disturbed from the beach. The water falling on to a cushion of water from the crest of a wave would, as before remarked, stir up the material of the beach more or less according to the thickness of the cushion and the size of the material. The chief horizontal movement likely to take place would be

due to the return waves flowing as an undercurrent down the slope. The material would therefore be carried seawards. The slope is here supposed to be fairly uniform from above the shore-line downwards; the case being, in fact, a beach, and not a shoal or bar on which waves break. The effect in the latter case would be different, there not being a return wave of a similar description.

27. The movement of the larger material down the slope is doubtless soon arrested. The flow from an incoming wave after breaking would cause most of it to be deposited at the point of meeting the return wave; or, on reaching the water-line, it would receive a check and be deposited; hence, large shingle is often not found below the water-line. Waves following at long intervals, or so as to allow the return waves full play, would allow large stones to be washed down to the water-line, or possibly a little below it. But waves following in rapid succession must check early the action of the return waves, and either prevent their taking up much material, or cause the deposition *above* the water-line of any large stones they may have moved. Small shingle and sand might be carried on, as the return wave would not, as before remarked, be destroyed. An incoming, or on-shore, wave passing over would, by causing an oscillatory motion, temporarily arrest the seaward motion, and might allow some of the material to be deposited, but the finer material would be carried on. Fine sand would probably be carried a long distance out. These results may be briefly stated as follows:—The coarser and heavier the material of the beach, the less it will be drawn below the water-line; the finer and lighter the material, the more readily it will be drawn below that line; the slope in each case being the same.

28. It would appear, then, from the foregoing remarks, that, theoretically, the shingle should be arranged in regular order on a beach, the largest stones at the water-line, or at the level where the force of the waves is greatest, that is, probably from a little above low-water level to a little above high-water level, and smaller stones higher up; the stones should also decrease very rapidly in size downwards under low-water level. The vertical cross section, or profile, of the shore tends to become convex above high-water level and concave below low-water level, and perhaps straight between the two levels. Practically, these results are not always arrived at, and when obtained they are seldom

lasting; the arrangement of the shingle on a beach is, as a rule, perpetually changing. Occasionally, a permanent arrangement may be met with, as, for instance, when a heavy sea, especially during a high spring tide, has thrown pebbles up to a position from which the ordinary waves may be unable to displace them.

(c.) *Action on the Bed of the Sea near the Shore.*

29. Water falling from the crest of a wave on to a cushion of water would, in stirring up the bed, cause some of the material to rise in the water. The deeper the water-cushion the greater the force necessary to disturb the bed, the material being the same. The particles, on approaching the surface, would be carried towards the shore by the waves (after breaking), or, in some cases, by the wind if blowing in that direction. The greater the force of the waves, as a rule, the coarser and heavier the material liable to disturbance. With a heavy sea and a gale blowing on shore, large stones might easily be transported from a considerable depth in the bed to the beach.

30. The greatest depth at which this action could take place is uncertain. It is often said that loose rubble is safe from disturbance at a depth of 15 feet; some say at any depth over 12 feet. The rubble foundation of the Alderney Breakwater was, however, disturbed at a depth of 20 feet below low-water level.* Much must depend on the size of the stones used for rubble. It is on record that "drift stones of large dimensions, measuring upwards of 30 cubic feet, or more than two tons in weight, have, during storms, been thrown upon the [Bell] Rock from deep water."† For shingle the above limits of depth are far too little. Sir John Coode remarked, after an examination of pebbles in the bed of the sea in front of the Chesil Bank:—"These facts demonstrate clearly that at a depth of 6 and 8 fathoms there must have been a considerable amount of motion during heavy gales."‡ The late Astronomer Royal concluded that in some places the stones on the beach "had been torn up by the violence of the surf from the bottom of the sea."§

31. The opinion of the late Astronomer Royal did not meet with general acceptance. It was controverted, as

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* *Proceedings of the Institution of Civil Engineers*, vol. xxxvii., pp. 74 and 108.
† Ibid., vol. vii., p. 333. ‡ Ibid., vol. xii., p. 535. § Ibid., vol. xxiii. p. 228.

regards shingle, by Sir John Coode in particular, who admitted the disturbance by wave-action of shingle at depths of 6 and 8 fathoms, but denied that the material was thrown up on to the beach.* The author, without pretending to decide a point on which such authorities are at variance, will venture to suggest that the difference is chiefly one of degree, since there are numerous instances recorded of stones being thrown up from great depths. Sir John Coode, therefore, could not have intended to deny the action *in toto;* he evidently meant that it did not take place to any great extent. At great depths, unless there is a projecting rock or other obstruction to the waves, there is little more than an oscillatory motion of stones, the size of large shingle, caused by even the heaviest waves at the surface of the sea, such waves not being waves of translation so long as the depth of water exceeds the height of the waves. Although these waves might not have power to transport to a distance stones of the size alluded to, a current of moderate strength could do so when the stones had once commenced to move, or had been lifted from the bed by wave-action. Now and then the stones might be carried within the influence of waves of translation, and might then be thrown up on to a beach or elsewhere. In this way, the facts just mentioned can be understood, while, at the same time, the results, as dependent on wave-action, may be looked upon as exceptional.†

32. A belt of discoloured water may often be seen along the shore when nothing but shingle is to be seen on the beach. This may be due to fine material carried downwards by the return waves (flowing off-shore as an under-current), or to material stirred up from the bed of the sea by the on-shore waves. The apparent width of this belt is not necessarily the extent to which material is held in suspension, because that on the surface is frequently in motion towards the shore. The attention of the author was drawn to the fact of this belt of discoloured water being sometimes wider in fine weather than in bad weather, the reverse of what might have been expected. The stronger wind in bad weather would, if on-shore, cause particles of matter floating, or in suspension near the surface, to approach the shore; the waves also would break further from

* *Proceedings of the Institution of Civil Engineers*, vol. xxiii., p. 241, and vol. xl., p. 107.

† See further illustration of this point in note on p. 79.

the shore, and carry towards the shore material in suspension near the surface. In fine and calm weather there would be less to obstruct the motion seawards of particles of matter held in suspension near the surface.

33. Even when the waves are not removing material from one part of the slope to another, the bed of the sea near the shore—that is, in shallow water—must be in a state of perpetual motion, unless the sea is too quiet to stir the material of which the bed is composed. The finer the material the greater the depth of water in which it would be moved. Coarser material at a considerable depth and heavy material near the shore might not be similarly disturbed except by a heavy sea. The author has observed this action on a small scale through clear water. The sand, a little way from the water-line, was continually oscillating up and down the slope—towards the shore as each wave came in, and away from it as the wave returned. With large waves the motion would be similar at a greater depth. It is almost certain that, at times, this disturbance takes place at a very considerable depth.

(d.) Relation between Wave-action and the Slope of a Beach.

34. The effect of the slope on the waves, or the action of waves on different slopes, may now be considered. Not only boulders and shingle, but sand, merely, is sufficient, under certain conditions, to withstand the force of the waves, even in the heaviest sea. It will, however, be observed that where the seashore consists of sand, there is a very flat slope; where the material is shingle or small stones, under similar conditions, the slope is greater; and where there are large stones or boulders, the slope may be very steep. It will also be observed that below the water-line in each case, as a rule, the slope gradually becomes less and less; and further, where there is shingle on the beach, smaller and finer material is usually found below the water-line, sometimes sand only, and not shingle, is to be found below low-water level.

35. It would seem that, as shingle or sand is carried alternately up and down the slope, and boulders also in a heavy sea, the normal slope in either case is that which allows the usual waves so to break as to move the material to the same extent both up and down. If a little material in excess is moved upwards at one time, the irregularity is corrected by

more being moved downwards at another time, and *vice versâ*. The less slope of the sandy shore destroys much of the force of the incoming waves a long distance out, and causes the waves to break before reaching the shore. Several broken waves, one behind the other, may be observed in almost calm weather rolling in at one time on to a sandy shore. Each incoming wave having to meet several return waves, the power of each to carry material one way or the other is, in consequence, to a great extent neutralised. With a similar sea coming on to a steeper beach of shingle, the waves break much closer to the shore; but the shingle is better able than the sand to withstand the greater shock. A heavier sea, in both cases, would break further out, and the incoming waves having to meet a greater number of return waves, the excessive removal of the material of the beach would be checked, as above explained, notwithstanding the greater power of the waves. Doubtless all waves coming into shallow water lose much of their force, before they break, in causing oscillation of the material forming the bed.

36. It will be interesting, and will serve to illustrate this point, to inquire what would happen supposing the waves to break with too great force on a shore of sand or shingle, or when the slope of either of these materials might be too great. It has been already shown that some of the material stirred up from the beach would be carried up the slope and some down it. The steeper the slope the less would be the quantity carried up the slope and the more that carried down it. That carried downwards would be more in the case of fine material than with coarse material. In this way the slope would gradually be reduced to that best suited to the material, or to that which would enable the material just to withstand the waves. The force of the waves would at the same time be lessened by the reduced slope. An equilibrium would thus be gradually established.

37. The reduction of the slope may be seen on any steep slope of easily yielding material exposed to wave-action. At the water-line the bank is cut into, and the material drawn down the slope. Of course, the case of a slope too steep to permit of the material when wet standing by itself must not be selected. Where the slope is not so steep as to cause the material to slip from its own weight, the material can only be carried down by the action of the waves. The slope is thus gradually flattened, and this goes on till the

slope becomes flat enough to withstand the wave-action. Increased force of the waves in a heavy sea probably has less effect on the slope than is usually supposed, if that slope be the one best suited to the material forming the beach; the increased force is destroyed by the waves breaking further out. More important points, in the opinion of the author, are the rapidity with which the waves follow one another and, more especially, the direction from which they come on to the beach. On the seashore, where the action of the waves is perpetually varying, the slope may often change; though the author is of opinion that other causes are usually at work when the changes are considerable.

38. If the above reasoning be correct, as the shingle becomes reduced in size, as will be presently explained, in moving along the coast, the slope of the beach should gradually become flatter. Further, so long as shingle remains on the beach any sand formed by attrition of the pebbles against one another is liable to be drawn under the water-line, and thus to be lost to view ordinarily. The observations of the author lead him to believe that these two propositions will generally prove to be correct. Where such is not the case, or where the slope of any beach differs much from that of a beach exposed to similar wave-action elsewhere, it is probable that some other agency is at work.

39. If the author may refer to the Chesil Bank in illustration of this point, he would suggest that the steep slope on the southern side of that bank is due to the strong current which flows round Portland Island. This slope at the south-east end of the bank is given at 1 in $5\frac{1}{2}$, sometimes increasing to 1 in $3\frac{1}{2}$; at the other end of the bank the slope is flatter. After a gale, the slope sometimes decreases to 1 in 9. The slopes observed by the author in New Zealand, when the beach had its normal slope —that is, when it was not being denuded of shingle—was about 1 in 10, decreasing when the material became finer to probably 1 in 15, or thereabouts. When the shingle was being carried forward rapidly, a portion of the slope might become as steep as 1 in 4, but this was only temporary. More definite information regarding the normal slope of shingle is required.

(*e.*) *Illustrations of the Foregoing Remarks.*

40. It may serve to make clearer some of the foregoing remarks to state here the result of an examination, by the

author, of the beach along the Western Spit at Napier, about the time of high-water. Waves were coming from the north-east, and were breaking some few hundred feet off the most exposed part of the beach, the trend of which was north-west and south-east. Now and then as many as four broken waves were to be seen at a time one behind the other, although there was very little sea beyond, and elsewhere the waves were not breaking till close in shore. Coarse sand was on the beach, the slope of which was very easy. A short distance (100 to 200 yards) west, the waves were breaking directly on the beach, which was running in the same direction; the slope was steeper, and there was shingle, not sand. Further west, the beach curves towards the south-west, and then to the south. Here the waves scarcely broke; there was little more than a wash along the beach; the material was sand, with shingle higher up. In a sheltered bay further west the beach, running north and south, was steep, and formed of shingle; no waves were breaking on it. On going partly round the bay to where the beach runs east and west the waves were beginning to break again; the slope was flatter, and the material was coarse sand once more. Further round, where the beach trends to the north-north-west, there was fine sand, with a very easy slope; two or three small waves were flowing on it at one time, the furthest out breaking at a height of about a foot. Large pebbles projected above the sand in places, and here, as at other places where there was sand near the water-line, there was shingle higher up the slope. Further on, the beach taking a north-westerly direction, the material was coarse sand, with small pieces of shell. Beyond this the trend of the beach was more northerly, and the waves were larger.

41. The coarse sand above mentioned was found on closer examination to be really very fine shingle. It was met with in other places also. It appeared to the author at the time to be deposited by waves coming directly on-shore, as mentioned in the Appendix (*c*) to this paper. The following explanation is suggested:—After the beach has been partly or wholly denuded of its surplus shingle, the slope would be reduced from the water-line upwards for a certain distance. On-shore waves would now throw up material from below the water-line without the power of carrying it down again.

42. Some observations as to the action of waves from different directions (on the Chesil Bank ?) were made by Sir

John Coode. The main points are given in an Appendix to this paper, with the results of observations by the author. The two do not agree; but the former, being applicable to the locality where the observations were made, may apply to some localities in this part of the world. Both are given, as they may be useful to other observers. To assist in this, remarks as to the chief points of difference are added (see *b* in Appendix).

(f.) Summary of the Foregoing Remarks on Wave-action.

43. The following is a summary of the foregoing remarks on wave-action on a beach:—

(1.) Waves breaking on any beach stir up some of the material, and carry a portion up the slope.

(2.) The return waves wash some material down the slope, the force of the waves rapidly increasing till checked.

(3.) Return waves may, or may not, move as large stones down the slope as the incoming waves carried up it, depending on the slope being more or less steep than usual.

(4.) A return wave is not destroyed on meeting an incoming wave; the two cross, and continue their course. But the motion of the material held in suspension by the two waves receives a check which tends to cause the deposition of the heavier particles.

(5.) Waves breaking obliquely on-shore cause the material to advance along the shore in the direction the waves take; but waves breaking directly on-shore merely cause the material to move up and down the slope without altering its position laterally.

(6.) The lower part of a wave breaking on-shore has probably a backward (off-shore) motion, tending to carry material away from the shore.

(7.) Waves breaking at a distance from the shore stir up the bed of the sea, and material is in consequence carried away from the shore by the return waves flowing as an undercurrent.

(8.) Waves so breaking cause some of the material forming the bed to rise in the water. Such material on approaching the surface is likely to be carried towards the shore.

(9.) The bed of the sea near the shore is in a state of continued oscillation, unless when the sea is too quiet to move the material.

(10.) If the slope of the shore be too steep for the material of which it is composed, the waves have a tendency to draw material down below the water-line—that is, to flatten the slope. In consequence of this the force of the waves is reduced.

(11.) If the slope be too flat, material on being thrown up by the waves will be likely to remain on the beach, and thus the slope will be gradually increased. The power of the waves will be increased in consequence.

IV.—Movement of Shingle along the Shore.

44. The way in which the waves cause the shingle to travel along the shore having been explained, the effect of the varying directions of the wind, and of the waves resulting therefrom, on a coast of very irregular outline may be first noticed under this head. In connection with this matter, it must not be overlooked that waves on coming into shallow water have a tendency to shift round a little towards the coast, and thus strike more directly on a shore than the direction in which they are moving in the open sea would seem to indicate. Shingle will not only move at varying rates at different times, but on many, perhaps most, parts of the coast it will move sometimes in one direction and sometimes in the opposite direction, though, as a rule, there is decidedly a greater movement one way than the other. Waves will impinge at different angles on different parts of the coast, and will sometimes drive the shingle entirely away from an exposed point. In this way some cliffs, which are at times protected from the sea by a beach of shingle, are at other times much cut away. But even where a beach is never thus entirely denuded, very great differences in the quantity of shingle are generally noticeable at different times.

45. Another point not to be overlooked is that, although the quantity of shingle in motion may be constant, it may, nevertheless, appear to be different at different points. Where the trend of the coast favours a rapid movement one way, the width of beach is likely to be less than where the movement is less constantly in one direction, or the waves strike with less force. In other words, the sectional area would be in inverse ratio to the mean velocity.

46. As shingle is carried along it is gradually reduced in size; large stones are reduced to small pebbles, and small pebbles to sand. The softer the material the more rapidly the reduction takes place. This reduction is not, however,

regular along the coast. Where the movement along that portion of the coast fully exposed to the prevailing seas is rapid, the shingle might appear to be of one size for a long distance; where the trend of the coast is different—is partly sheltered from the prevailing seas, or is much exposed to seas from other directions, giving rise to a contrary movement at times—the movement of the shingle in the prevailing direction being less rapid, it is likely to be reduced in size in a comparatively short length of coast.

47. Shingle may disappear at certain points of the coast-line notwithstanding the supply is continuous. It will be well to consider how this takes place. Wave-action does not ordinarily carry shingle of any size much below low-water level, except where, from some cause or other, a steeper slope than the normal exists. A current flowing round a point, or a current sweeping round a bay, may remove the finer material forming the base of the shingle, and may thus increase the slope. In such case some shingle will probably be carried below low-water level by the action of certain waves, as, for instance, waves breaking at long intervals, and allowing the return wave to act with the greatest effect. But, when the beach has its normal slope, shingle may disappear under the following circumstances:—

(1.) The fresh water, or tidal, flow at the mouth of a river or lagoon must carry below the water-line any shingle that may be thrown into the stream by wave-action or otherwise, especially at the point of each tongue of shingle, which is generally formed where a break in the beach occurs from the above cause.

(2.) As the shingle is worn and reduced in size, the finer particles are carried under the water-line, while the shingle remains on the beach.

(3.) Where a shingle beach appears to die out gradually, running into sand, the slope becomes flatter and flatter as the shingle changes to sand. Then, the sand, if not accumulating, notwithstanding the continued travel of the shingle towards the spot, must be drawn under the water-line, and tend to raise the sea-bed. It goes, in fact, as is very commonly the case, to silt up the head of the bay.

48. It may have been noticed in a former part of this paper that the formation of a lagoon by a strip of shingle beach is not unfrequent on these coasts. This occurs at a point where, before the shingle beach was formed, a deep indentation in the coast-line existed. Owing to the shore-

line suddenly receding, the wave-action must have been insufficient to drive the shingle along the shore of the bay as fast as it accumulated at the commencement of the indentation in the coast-line. The shingle would then be deposited in a line between the points of the shore terminating the bay. No such action takes place, ordinarily, across the mouth of a bay when the waves can break fairly on the shores of the bay, as in Caroline Bay at Timaru, and at the present time north of Napier. Other instances are to be found where the shore-line, along which shingle is moving, suddenly recedes and, being protected in some way, the wave-action is insufficient to drive the shingle along the receding shore-line as fast as it accumulates at the point. The point will then advance steadily further and further out. This was probably the action going on south of Napier before Scinde Island was connected with the mainland. Similar action is going on at Hurst Castle and Dungeness, on the south coast of England, and at other places.

49. As the action at the mouth of the River Ngaruroro, six miles south of Napier, is due to a similar cause, the case may here be briefly described. The mouth of this river has been for some time past shifting steadily northwards, the shingle travelling from the southwards. The shore behind the shingle is formed of earth, and would be easily cut away but for the shingle beach in front. The line of the beach is fixed, and could be altered but slowly. The stream from the river having first worked as far northwards as the bank would allow, began to cut away the bank and to form a channel behind the shingle.

50. This has gone on, the river near the mouth having changed its course, extending further and further north, parallel with and behind the beach, and cutting away more and more of the original shore, and would go on indefinitely if there were only a steady fresh-water stream to form the current. When heavy floods come down the river at intervals, a fresh mouth is opened through the shingle, when the water can more easily escape in this way than along the channel. The old mouth of this channel is then quickly closed up by the shingle, and that opened by the flood continues in use; but, as before, it gradually shifts more and more to the north, and the same action as before goes on. If the channel were kept open by the tidal flow, this flow would gradually become less and less as the channel lengthened, and the mouth of the channel

would get smaller, and at length it would close up altogether. Several of the smaller rivers on the Ninety-mile Beach appear from the chart to be so circumstanced (see par. 10). The water of the rivers then would either filter through the shingle, or it would accumulate till it was able to force its way through now and then.

51. The mouth of the River Tuki Tuki, two miles south of the River Ngaruroro, is at present more constant than that of the latter river. The author attributes this to the very large mass of shingle which is lying in front of the former river. The tendency is for the mouth to shift northwards, but the large mass of shingle is not quickly cut away, and, before any great change can be made, a flood coming down the river brings the opening in the shingle opposite the mouth of the river once more. It is easier for the smaller river, Ngaruroro, to cut away the earthen bank, than for the larger river, Tuki Tuki, to cut away the shingle. The author was informed that several rivers of New Zealand are subject to frequent and heavy floods for a series of years, and then the reverse is the case for another series of years. This is expressed, in other words, by there being a cycle of wet seasons at intervals. When the time comes for the floods of the rivers to be less for a few years in succession, the shingle will be less frequently broken through, and then the mouth of the River Tuki Tuki may shift like that of the River Ngaruroro; probably both will have one and the same mouth for a time.

V.—Movement of Shingle Below the Water-line.

52. This is a matter upon which the author is not prepared to say much. Although there may not ordinarily be any tendency for the shingle to descend below the water-line, so long as the beach is continuous and has its normal slope, and the movement of the shingle is unobstructed, this will happen when a sudden change in the trend of the coast-line occurs, as mentioned above (in par. 48), or when a break occurs in the beach at the mouth of a river or other channel which is kept open by a strong current of water. In such a case a spur is formed in the direction the shingle is moving. This extends a certain distance, depending on the strength of the current and the force of the waves; the current has to force its way on the one side, and the waves of the sea on the other side either driving the shingle towards

the shore or keeping it in the direction necessitated by the slope of the bed of the sea. The shingle is at length forced over into the water, and forms a bar where the waves break; over this the current from the river flows.

53. The shingle being forced into the water would fall to the bottom as soon as the forces acting on it failed to keep it in suspension. Here it would accumulate till it raised the bed or formed a bar across the channel just sufficient for the current to pass over it without disturbing it. Any shingle in excess of this washed into the bed would, with the current on the one side and the waves on the other, be forced across the channel, when it would be thrown up again on to the beach. It is impossible here to analyse the action going on; it must suffice to state the fact.

54. The depth at which this action would take place would vary according to circumstances. Thus, before the channel leading to the inner harbour at Napier was contracted by the present moles, the bar was at times not more than 4 or 5 feet at low water. It will obviously be as little as the current will permit. The important point to ascertain is, what is the greatest depth at which the action will go on?—in other words, what depth can be obtained and maintained over a bar where there is travelling shingle? Reverting to the case of the Napier channel, all attempts to keep it clear have, except when the shingle was trapped for a time behind the east mole, failed to secure for any length of time a greater depth than 8 or 9 feet at low water. During westerly weather, in the summer, a foot or two more may be obtained; but the depth is reduced by heavy easterly weather. There is a very strong current through the channel—six to seven knots an hour in mid-stream—and yet the above-mentioned depth only is obtainable. A slightly weaker current might not make much difference; but if the current could be reduced considerably in strength, the depth of water over the bar would certainly decrease. A stronger current would probably cause the bar to move further from the mouth without improving the depth in any way; or it might increase the depth, and at the same time form a long spit in a direction between that of the beach and that of the stream, diverting the latter and causing the channel to curve round.

55. Mr. C. H. Weber, late engineer to the Napier Harbour Board, who very carefully observed the action going on in Hawke's Bay during many years, prepared a memorandum

for the information of Sir John Coode, which is dated 20th March, 1879. In it he remarked:—"The depth at which the shingle travels can be judged to some extent from the difference in the soundings north-west of the Bluff. The cavities in the bottom, 15 feet below water, are found emptied of shingle after easterly weather." Around the Bluff the sea has "a very uneven bottom, which traps the shingle in its journey round the Bluff. Soundings have proved that, in this very exposed locality, shingle travels to the depth of fully 18 feet."* It may be open to question whether the movement of shingle at this depth is due entirely to wave-action, or is partly due to a current flowing round the Bluff;† also, whether much of this shingle is thrown up again from a depth of 18 feet on to the beach or not. Much depends on the size of the waves at the point.

56. The important point to consider here is, whether the fact of shingle shifting at a depth of 18 feet at the Bluff can be taken as evidence that it would cross the bar at the entrance to the present harbour at such a depth or not. In face of the other facts before referred to‡—that during westerly weather (when the shingle would be driven backwards) the depth increases, but easterly weather (which drives the shingle forward) reduces the depth again—the author cannot admit that any such depth on the bar could be maintained so long as the supply of shingle is unchecked. If this depth were obtained in any way, the author is of opinion that the shingle would not cross the entrance; it would accumulate till the bar became nearly as at present, and then it would begin to travel once more.§

57. A depth of 8 to 10 feet would therefore appear to be the maximum at which the shingle can travel freely in this case. Under altered conditions a different depth would perhaps result. Further observations are necessary before anything more definite can be stated on this point. One thing, however, is scarcely open to question: no harbour suited to vessels of any size can be secured where there is travelling shingle, unless means be adopted to keep the shingle from the entrance.

Concluding Remarks.

58. The following deductions from the foregoing remarks regarding shingle on the beaches visited by the author are

* See note on p. 79. † See par. 31. ‡ See par. 54.
§ See Appendix II., at p. 84.

given as a summary. Many of these deductions may be of general application :—

(1.) Shingle is caused to move up and down the slope of any beach by the action of the waves, and is reduced in size by constant attrition.

(2.) Shingle is caused to travel along the coast by waves striking obliquely on the shore.

(3.) Shingle of any considerable size is rarely carried much below the water-line by wave-action alone. On the contrary, waves tend to throw up on to the beach material from the bed near the shore. At times very heavy stones have been so thrown up. The finer material is carried down again by the return waves.

(4.) There is a certain slope, peculiar to each size of shingle, which may be called its normal slope, and which enables a shingle beach best to withstand the action of the waves. The larger the shingle the steeper its normal slope, and *vice versâ*.

(5.) The *tendency* of wave-action is to arrange the shingle in regular order on a beach, as follows :—

- (*a*) The largest pebbles to collect near the water-line, or between the levels of high and low water. The size should diminish slightly from high-water level upwards, and very rapidly from low-water level downwards.
- (*b*) The slope will be steepest between the levels of high-water and low-water. Above high-water level the beach will assume a convex shape; below low-water level the profile of the bed will be concave.
- (*c*) With a slope flatter than the normal, the largest shingle ought to be at, or above, high-water level. With a slope steeper than the normal, the large shingle should be looked for near low-water level.
- (*d*) If the slope differ from the normal, the wave-action tends to restore the slope, reducing it if too steep, and increasing it if too flat.

The theoretical results are seldom attained, owing to the perpetual changes going on. The longer the forces at work remain constant, the nearer the theoretical condition is approached.

(6.) When the shore runs in one, or nearly one, direction for several miles, without any projecting points or bays to break the uniformity of the coast-line, shingle will be uniform in its character.

(7.) Where the coast-line is irregular so that the movement of shingle is likely to be arrested at times, great changes in the beach may be looked for. The shingle will sometimes accumulate, and at other times the excess will be removed. In places the beach may be almost, or entirely, denuded of shingle.

(8.) When an accumulation of shingle takes place at any point, the beach is raised. This may be called a "high" beach. In this case low-water mark may extend further out from the shore than usual.

(9.) When the surplus shingle is in process of removal, being carried along the coast, a flat slope is formed from the water-line upwards. This may be called a "low" beach. At the upper edge of this low beach is a steep slope between the low beach and the high beach. This slope gradually recedes further and further from the water-line till the surplus shingle is entirely removed.

(10.) A high beach will have a steeper slope, and will consequently be formed of larger shingle, than a low beach.

(11.) Shingle is lost from the beach as follows:—

(*a*) By being carried below the water-line by streams, flowing across the beach into the sea, and by wave-action at each projecting point of the beach.

(*b*) By the finer particles being separated from the shingle, and drawn under the water-line all along the coast.

(*c*) By the remainder being gradually reduced to sand.

(12.) When the supply of shingle at any point, where its movement along the coast is arrested, is too great to permit of the whole being reduced to sand, the shingle accumulates. If this accumulation occurs against a cliff, or where waves break with great force, a high bank is likely to be formed; but if the accumulation occur where the ordinary wave-action on a beach takes place, the shingle is arranged in successive ridges one in front of the other.

(13.) Where there is travelling shingle, a bar will form under the following conditions:—

(*a*) Across the entrance to a river or lagoon. The depth of water over this bar is not likely to exceed 8 or 10 feet at low water.

(*b*) From any point where the trend of the coast-line suddenly changes, or from the end of any jetty or other similar projection from the shore.

(14.) Shingle may travel in other situations at considerable depths. It has been observed to do so to a limited extent at as great depths as 6 and 8 fathoms. But whether shingle is thrown up again from such depths on to the beach is doubtful.

(15.) These propositions need to be confirmed by further information before they can be considered of general application.

59. This paper has extended to a much greater length than the author anticipated, and is not so complete or satisfactorily arranged as he would have liked. He trusts, however, that it may not be without interest to members. Much remains to be learnt regarding the movements of shingle, even in the cases dealt with in this paper. Observations elsewhere require to be made before general conclusions can be safely drawn. The author has, nevertheless, attempted to generalise to some extent, in order that others may be the better able to make use of what he has written; for a bare relation of facts of this nature is, as a rule, of very little use unless the facts are connected and the principle underlying them explained in some way. The author trusts that any errors into which he may have fallen will be pointed out, and that some one else having opportunities of observing the action of shingle will be induced to give some further information on the subject.

60. To facilitate the collection of information of an uniform character, a few points which ought to be noted are mentioned in the Appendix (*e*—p. 84). Such particulars collected from different localities would be comparable and would probably soon remove most of the difficulties which now surround the subject.

Note to Par. 55, regarding Wave-action at considerable depths (see also par. 29 *et seq.*) :—

On a rocky bottom, small stones and sand would be very liable to be scooped out of crevices and hollows and forced to rise to the surface by wave-action; while a similar result would not take place, at the same depth, on a homogeneous bottom, which would yield equally in all directions. A rocky bottom would reflect the waves.

APPENDIX.

(See par. 42.)

(1.) Result of Sir John Coode's Observations of Wave-Action on Shingle.

(a.) Extracts from Proceedings of the Institution of Civil Engineers (Vol. XII. pp. 539-541):—

"An examination at low-water with the wind off-shore, or just along the shore, will show that, as a rule, the largest shingle to be found on any particular beach, at that particular time, is just about the level of the previous high-water, or so far above it as the wash of the previous tide may have extended; and the size decreases from this down to low-water."

"After the prevalence of heavy on-shore winds, or a 'ground-swell,' the large shingle will be found to be entirely scoured away from the beach." "Shingle accumulates upon any beach with off-shore winds, whilst it is carried off, or scoured away, during on-shore winds, and more especially by the ground-swell which follows."

"Seven, or any less number of waves per minute, indicate the destructive action, and nine, or any greater number, the accumulative action; but no very precise rule can be framed upon this basis." "A more certain indication is found by watching the course of the water as it falls from the crest of the wave after breaking. If it falls upon the water which may be returning down the slope from the wave immediately preceding—as it will do when the waves follow in rapid succession—this may be taken as an evidence that the accumulative action is going on. If, on the other hand, the water descends directly upon the pebbles—as is the case when the waves break at comparatively long intervals—it carries down with it a portion of shingle, and is, in fact, a case of destructive action."

The cross-section or profile of the Chesil Bank, near the west end, taken after a gale, was very nearly a "parabolic curve from a point more than 25 feet above high-water level down to a little below high-water level." The slope between high-water and low-water levels was, after the same gale, "slightly flatter than 1 in 9; and precisely the same inclination has been observed, within the same limits, after a heavy ground-swell. . . . After a continuance of off-shore winds for two or three days, the case is very different. Under such circumstances, the shingle takes a perfectly uniform inclination, within the limits of the tidal range, and lies generally at a slope of 1 in $3\frac{1}{2}$ to 1 in 4."

(b.) Remarks by the Author on Sir John Coode's Observations.

The "on-shore winds" would, as a rule, be accompanied by waves from the same, or nearly the same, direction as the wind, and striking the shore obliquely or at right angles as the case may be; but the "off-shore winds," or winds just along the shore, would be accompanied by waves from some other direction than that from which the wind might be blowing. Whether the waves strike the shore obliquely or nearly at right angles—very important considerations in relation to the movements of shingle—is not known from the description given by Sir J. Coode. In all cases, it would be far more satisfactory if the direction and character of the waves, rather than of the winds, were described. The term "ground-swell" also is vague.

The scouring away, or destructive action, mentioned by Sir J. Coode, is, in the opinion of the author, really the surplus shingle, which has been accumulating for a time, being carried forward by waves striking the shore obliquely. This gives the appearance of some having been cut out, leaving a steep slope above the water-line. The sectional area of the shingle in motion is simply reduced to correspond with the more rapid advance of the shingle. In the case of the steep slope of the Chesil Bank (1 in $3\frac{1}{2}$ to 1 in 4), the general action of on-shore *waves*, especially if following one another at long intervals, must be to cut into the bank—that is, to reduce the slope above the water-line.

With regard to the effect of waves striking the shore at different intervals, another observer, Mr. H. R. Palmer, remarked—"that when ten breakers arrived in a minute, the destructive action was but just commenced, and when only eight breakers . . . the pebbles began to accumulate." These results, it will be observed, differ from those stated by Sir J. Coode. Perhaps Mr. Palmer referred to the lower part of the beach, and Sir J. Coode to the upper part.

The water falling from the crest of a wave after breaking "upon the water which may be returning down the slope from the wave immediately preceding," is understood by the author to mean a meeting of the waves on the slope, in which case the downward movement of material would be arrested, and the cutting-out action consequently prevented. Any shingle thrown up by the waves would then remain on the beach. When "the water descends directly upon the pebbles, as is the case where the waves break at comparatively long intervals," the return waves are able to act with full effect, and, the slope being steep, the destructive action goes on freely.

(2.) Results of Observations by the Author.

(c.) *Results Noted.* (See par. 41.)

The author did not notice the different effects of off-shore and on-shore winds, as above; but the difference resulting from waves coming *obliquely* on-shore, and from those coming *directly* on-shore or striking the shore nearly at right angles, was most marked, particularly near the time of high-water, when the lower portion of the beach would be submerged.

Waves coming obliquely on-shore appeared to scoop out the shingle, to throw back the beach, and to form a steep slope with large shingle on it. These observations apply more particularly to the upper part of the beach; the lower portion, when it could be observed, was usually flatter than before.

Waves coming directly on-shore, or striking the shore nearly at right angles, appear to form a flatter slope, to widen the beach, and often to cover it with fine material, which when wet appeared from a little distance like mud; but on close examination it was found to be coarse sand, formed of material similar to that of the shingle. These waves would draw down the shingle from the steep slope formed by waves striking the shore obliquely, and raise the lower part of the beach; and further, as material is not carried along the shore by these waves, fine shingle or coarse sand thrown up on the lower and flatter part of the beach must remain there.

(*d.*) *Modifications of the above probably necessary under certain conditions.*

The author doubts whether the effect of waves striking the shore, either obliquely or at right angles, would be always as above. The results stated were observed shortly after there had been a full beach, surplus shingle having formed what may, perhaps, more accurately be described as a high beach. Consideration of the subject, since the observations were made, leads the author to believe that after the denuding of the beach of its surplus shingle and the forming of a low beach, the result of waves continuing to strike the shore obliquely would depend chiefly upon whether there were, or were not, a further supply of shingle ready to be carried on to the portion of the beach under observation; that is, whether there were surplus shingle lying near on the side from which the waves were moving or not.

If there were a further supply of shingle, the lower part of the beach would probably not be flattened to any great extent by waves striking the shore obliquely; or, if flattened for a time during changes in the weather, it would be covered shortly with fresh shingle. If there were no further supply of shingle, the beach would be still further denuded, would be reduced in width and have a still flatter slope; the material would probably become smaller and smaller and in time perhaps sand only would be visible above the water-line. This action would go on till the beach disappeared altogether, or became so much reduced as to afford no protection to the shore which, if of yielding material, would begin to wear away.

The result of waves striking the shore nearly at right angles, when there was a full beach down to low-water level, would probably not be noticeable during a short period of time, unless in the exceptional case of the slope below low-water level being steeper than above that level. In such a case, these waves would tend to draw the material downwards, make the beach wider, and gradually reduce the slope. Fine material would not be thrown up unless the slope became very flat from some other action going on at the same time. Long continued action of waves nearly at right angles on a full beach would gradually reduce the material by constant attrition; the finer particles would then be drawn downwards under the water-line. In this way, shingle moving towards one part of a beach may slowly disappear, instead of accumulating, as it does when the supply is too large to be all disposed of in this way.

(*e.*) *A few points to be noted when observing the movements of shingle.* (See par. 60.)

Besides the main features of the locality and the state of the weather at the time, it is important to ascertain what the weather for a few days previously has been, and the corresponding action on the beach. Not only the direction of the wind but the direction of the waves with reference to the shore should be noted. The approximate height of the waves, the number of waves per minute, and whether the water falling from the crest of the waves, as they break, strikes directly on the beach or on to a cushion of water, may be usefully observed. The general form of section, or profile, of the beach should be recorded, with the state of the tide at the time of observation, remembering that, except at low-water, the whole of the beach would not be visible. Any information regarding the material and slope below the water-line, when obtainable, is likely to be particularly useful and instructive. Observations should be carried on for as great a length of beach as possible, carefully noting the bearing of different portions, if not uniform, and ascertaining whether the beach is full or empty at each part, or, in other words, whether there is more or less shingle than usual.

Appendix II.

Travel of Shingle below the Water-line.

(See par. 56.)

Since writing the paper, the author has come across a case where the travel of shingle is interrupted by deep water. This occurs at Harwich, on the east coast of England. Shingle works down the coast from the north and has formed, partly across the combined mouth of the rivers Orwell and Stour, a long spit called Landguard Point, which advanced in a southerly direction some 700 yards between the years 1760 and 1865. In the last twenty-five years of this period, the advance was nearly 300 yards; this rapid elongation being accompanied by a thinning out of the point, there being an evident tendency to form a long spit entirely across the mouth of the channel, as has occurred a few miles to the north of Harwich. The *North Sea Pilot* states that between 1804 and 1826 there was "a narrow seven-fathoms channel close to the walls of Landguard Fort." In 1826, the point advancing, gradually "reduced the available depth into the harbour to 11 feet." About 1845, dredging was commenced; this has increased the depth to 17 feet at low-water springs, which was the depth in 1874.

The point to which the author wishes to draw special attention is that at one time no shingle seems to have crossed the channel. Then, as the depth was reduced, shingle began to give trouble on the south side; and latterly, it would appear from various accounts, the shingle has decreased again. The conclusion forced on one is, that with a depth of 11 feet, some shingle crossed the channel, but that with a depth of 17 feet or 18 feet it does not cross under ordinary circumstances. During heavy weather, some small quantity may be carried across the increased depth.

It may be interesting to note here that sand has formed a similar spit, called Spurn Point, partly across the mouth of the River Humber. The depth at which this material can cross the channel would appear, from the soundings given on the chart, to be from 40 feet to 45 feet.

These two instances are not conclusive, because the chain of circumstances is not as complete as could be desired; but they help to support the author's arguments. They show that shingle does not cross freely a channel the depth of which exceeds 11 feet or so, and that the lighter the material the greater the depth at which it can travel. It may be remarked here that the shingle on the east coast of England is, by all accounts, smaller than that on the east coast of New Zealand. In this case, the former would be able to travel at a greater depth than the latter.